



WATER ACQUISITION AND ROOTING CHARACTERISTICS IN NORTHERN AND SOUTHERN POPULATIONS OF *GUTIERREZIA SAROTHRAE*

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Wan C. G., Sosebee R. E. and McMichael B. L. *Water acquisition and rooting characteristics in northern and southern populations of *Gutierrezia sarothrae**. *Environmental and Experimental Botany* **35**, 1-7, 1995.—Seeds from northern (Idaho) and southern (New Mexico and Texas) populations of broom snakeweed (*Gutierrezia sarothrae*) were germinated in a greenhouse and the seedlings grown in a soil mixture in 30-cm deep (19-l) plastic pots for 50 days. The pots were then fastened onto the top of similar pots and the seedling root systems were allowed to grow into the lower pots for 4 weeks through punctures in the bottoms of the upper pots. Soil water extraction from four different depths was measured using time domain reflectometry (TDR) 2 weeks after roots had begun to grow into the lower pots.

The two New Mexico populations (Jornada and Mountainair) and a population from Plains, Texas extracted more water from deeper (≥ 38 cm) soil layers than the Idaho population ($P < 0.05$). Root length in the deeper soil layers (55-60 cm) was greater ($P < 0.05$) for the Jornada desert population than for the Idaho and Mountainair populations. The Plains population had shorter roots and extracted less water in the upper soil layers than the other populations ($P < 0.05$). Specific root length in the Idaho population was at least 67% greater ($P < 0.01$) than those in southern populations, indicating smaller root diameters. The patterns of soil water extraction and root penetration were correlated with the seasonal distribution of precipitation in the plants' natural habitats. The Idaho seedlings had roots confined primarily to the topsoil to secure water from spring precipitation. In contrast, some southern seedlings were able to develop an extensive deep root system to avoid spring drought.

Key words: Broom snakeweed, ecotype, root growth, drought, desert shrub, water use.

INTRODUCTION

Broom snakeweed [*Gutierrezia sarothrae* (Pursh) Britt and Rusby] (Asteraceae) is widely distributed across

North America, with the largest population density in the southwestern United States. It is an aggressive invader of semiarid rangelands of the Southwest, and herbaceous vegetation declines as the shrub

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increases. Northern populations do not seem as competitive in their native habitats within the Great Basin Desert. Considerable ecotypic variation in *G. sarothrae* might be expected between northern and southern populations. Population differentiation has been observed for a variety of species.^(24,30,21,22,12,15,16,17) However, there are few intraspecific comparisons of water uptake and root growth in the literature. Root competition for soil moisture can strongly influence competitive effectiveness of a species on semiarid rangelands.⁽¹⁰⁾ Thus environmentally-imposed variations in water acquisition patterns and root penetration in early growth in southern vs northern populations of *G. sarothrae* could, to some extent, explain differences in plant behavior in their respective environments.

Gutierrezia sarothrae has long been recognized as a shallow-rooted half-shrub in the Midwestern United States.^(28,7) Weaver⁽²⁸⁾ suggested that this was an adaptation for securing water from light rainfall in the dry plains soil. However, some reports indicated that growth and photosynthesis in *G. sarothrae* on west Texas rangeland were closely associated with water uptake by deeper roots.^(25,26) *Gutierrezia sarothrae* appears to outcompete grasses through more rapid water uptake from the subsoil.⁽²⁶⁾

In a field study, approximately 15% of daily water loss through transpiration of *G. sarothrae* was shown to be taken up by deeper roots at night and deposited in the upper soil where it was subsequently absorbed by shallow roots.⁽²⁷⁾ Perhaps southern populations are able to exploit subsurface stored water more effectively than the northern populations. If so, they may have more rapid root penetration into deeper soil during early growth stages. This study was an attempt to test this hypothesis. A greenhouse experiment was conducted to measure: (1) water extraction from four different soil depths by 2-month-old seedlings of three southern populations and a northern population of *G. sarothrae*; and (2) root growth in the 0–30-cm soil depth and root penetration from the 30–60-cm soil depth during a 4-week period.

MATERIALS AND METHODS

Seeds of *G. sarothrae* used in this study were collected in 1991 from four populations in different geographical locations (Table 1).

Seeds from the four populations were germinated

in soil in a greenhouse, with temperatures ranging from 15 to 30°C. At least 20 seedlings were obtained from each population. Single seedlings were transplanted into a 50:50 mixture of sand and a commercial greenhouse mix (Metro-Mix 702 growing medium) in 19-l plastic pots that were 30 cm deep. The pots received 500 g of water every other day, or 114 mm per month, which was at least 74% more than the maximum monthly precipitation in the native habitats of the four populations. Fifty days after germination, the root systems of all seedlings extended to the bottom of the pots. Four pot-grown seedlings were randomly selected from each population and 10 regularly-positioned holes, 1-cm diameter, were drilled into the bottom of each pot, and the pot was fastened on top of another similar pot. The bottom pots were filled to the top with a similar soil mixture and weighed about 19.4 kg each at field capacity. The initial moisture content in the lower pots was at field capacity and no additional water was introduced during the experiment.

Soil water depletion from the upper and lower pots was monitored with time domain reflectometry (TDR)^(23,6,13) 14 days after the plant roots were allowed to grow into the lower pots. Two stainless steel rods, 0.32 cm in diameter and 20 cm in length, were inserted vertically at a parallel distance of 5 cm apart into the soil of each upper pot. Three additional pairs of rods were similarly installed horizontally into each lower pot at depths of 38, 48 and 58 cm. Because TDR measures water content for a soil column with a diameter that is 1.4-times the distance between the rods,⁽²³⁾ the soil volume measured with this technique was approximately 770 cm³. Soil electromagnetic capacitance and reflectance patterns were measured with a Tektronix 1502C TDR cable tester (Textronix, Beaverton, OR, U.S.A.) connected to the soil probes. The cable tester readings of electromagnetic wave length were converted to dielectric constants (k) using the method described by Dalton and Poss.⁽⁶⁾ Soil volumetric water content (Q_p) was calculated from k , using the empirical equation: $Q_p = -0.053 + 0.0292k - 0.00055k^2 + 0.0000043k^3$.⁽²³⁾

Soil water content was measured every other day for all four populations at midday for 14 days before the Idaho population entered the reproductive phase. Root length in the bottom of the lower pots should represent the populations' root penetration capabilities. Total root length at the 55–60 cm soil

Table 1. *Geographical locations and environmental conditions of four G. sarothrae populations*

Location	Latitude	Longitude	Elevation (m)	Precipitation (mm)	Ecosystem
Malta, S. Idaho	42°18'N	113°17'W	1376	279	Great Basin Desert
Plains, W. Texas	33°11'N	102°50'W	1115	412	short grass plains
Mountain-air, NM	34°31'N	106°15'W	1976	265	borders on shortgrass edge of plains and Rocky Mountain foothill vegetation type
Jornada, S. NM	32°37'N	106°44'W	1293	228	Chihuahuan Desert

Table 2. *Analysis of variance for soil water content (g cm^{-3}) in pots occupied by plants from four populations of G. sarothrae*

Source of variance	df	0–20 cm		38 cm		48 cm		58 cm	
		F	P	F	P	F	P	F	P
Population	3	3.38	0.068	19.9	0.0003	6.4	0.013	6.96	0.010
Block	3	108.2	0.0001	65.0	0.0001	118.8	0.0001	75.6	0.0001
Pop. \times Block	9	62.5	0.0001	30.5	0.0001	140.1	0.0001	51.6	0.0001
Time	6	38.4	0.0001	49.4	0.0001	32.3	0.0001	49.6	0.0001
Pop. \times Time	18	1.84	0.037	4.1	0.0001	1.04	0.42	1.58	0.09

depth was determined with a Comair optical scanner (Hawker Dehavilland, Inc., Australia) at the end of the experiment. Total root length in the upper pot was also determined for the four populations using the same method. Specific root length, defined as root length per unit dry weight (m g^{-1}), was calculated. The transpiring surface area of the leaves and green stems at the end of the study was measured with a Licor-3100 leaf area meter.

Four randomly selected individuals from each plant population were used in the measurements. Since the plants were arranged along a vapor pressure gradient in the greenhouse, a randomized block design with repeated measures analysis was used to test differences among populations in water extraction. Since our hypothesis predicts a directionality to the expected results, one-tailed *t*-tests were used to separate means for water extraction, root length and canopy area development.

RESULTS AND DISCUSSION

There were significant differences between populations in soil water content at the deeper soil layers (Table 2), whereas the differences were marginally

significant in the top 20-cm soil. At the 0–20 cm depths, water content was higher for the Plains (PL) population than for the other populations ($P < 0.05$). At the 38-, 48- and 58-cm depths, water content was the lowest in soil for the Jornada (JN) population and highest in soil for Idaho (ID) population, with Mountainair (MT) and Plains (PL) being intermediate. Since the lower pots were initially kept at field capacity for all populations, the slopes of water depletion were steeper in the populations from New Mexico and Texas (JN, MT and PL) (Table 2 and Fig. 1).

A negative linear relationship ($P < 0.01$) existed between log root length and soil moisture content (Fig. 2) in the bottom of the lower container, as would be expected. The Jornada population had greater root length than the Idaho and Mountainair populations in the bottom of the lower container (Fig. 3). The Plains population had a shorter root system in the 0–30 cm depth (Fig. 3, $P < 0.05$), which was consistent with less water extraction from the top soil (Fig. 1). Specific root length was lower for the three southern populations (ranged from 34.2 ± 1.8 to $38.0 \pm 2.2 \text{ m g}^{-1}$) than from the Idaho population ($63.3 \pm 4.8 \text{ m g}^{-1}$, $P < 0.01$), suggesting

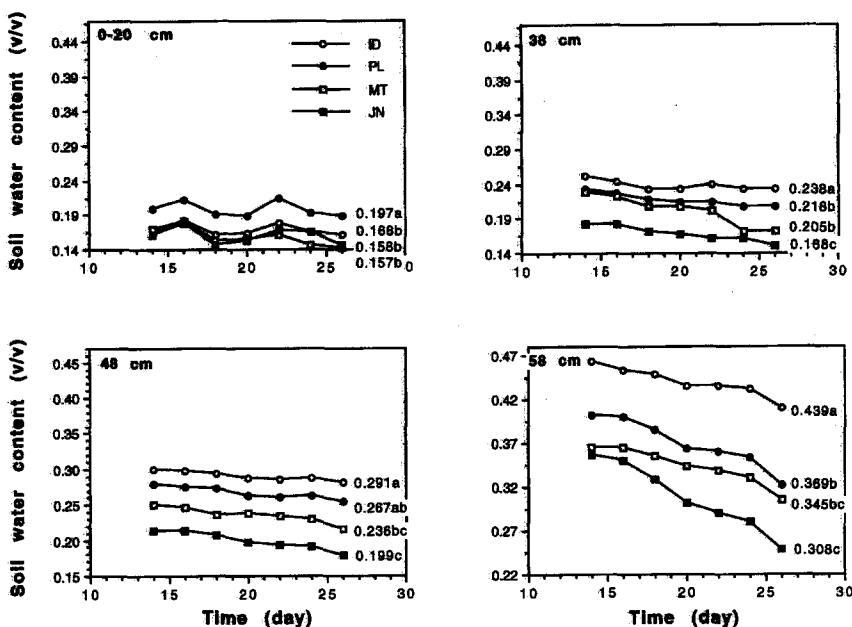


Fig. 1. Changes in soil water content (v/v) of four populations of *G. sarothrae* at four soil depths. The mean values followed by the same letters are not different ($P > 0.05$). The horizontal axis indicates how long the plant roots were allowed to grow into the lower pots. ID—Malta, Idaho; PL—Plains, Texas; MT—Mountainair, New Mexico; JN—Jornada, New Mexico.

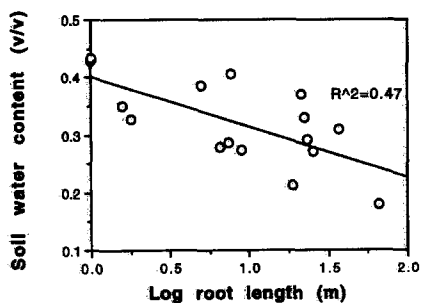


Fig. 2. Relationship between log root length and soil water content in the 55–60 cm soil for four populations of *G. sarothrae*.

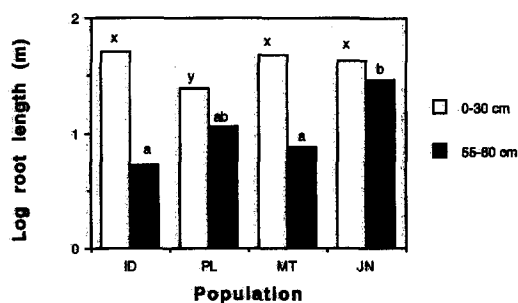


Fig. 3. Log root length in the 0–30 cm and 55–60 cm soil for four populations of *G. sarothrae*. ID—Malta, Idaho; PL—Plains, Texas; MT—Mountainair, New Mexico; JN—Jornada, New Mexico. Means followed by the same letters within the same soil layer are not different ($P > 0.05$).

larger root diameters in the southern populations. Inability of the Idaho population to extract water from the moist deeper soil layers might be related to its thinner roots and poor root penetration into these layers.

The northern and southern populations are adapted to their environments where mean

maximum daily temperatures in the growing season are quite similar (34–40°C).⁽¹⁸⁾ Midday photosynthetic active radiation in the summer ranges from 1400 $\mu\text{mol m}^{-2} \text{s}^{-2}$ in the Great Basin Desert⁽³⁾

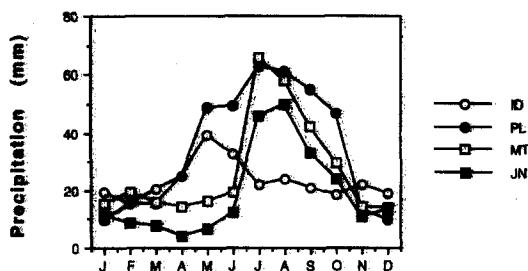


Fig. 4. Average monthly precipitation (at least 39 years records from Climatological Data, National Oceanic Atmospheric Administration) for the four *G. sarothrae* habitats. ID—Malta, Idaho; PL—Plains, Texas; MT—Mountainair, New Mexico; JN—Jornada, New Mexico.

to about $2000 \mu\text{mol m}^{-2} \text{s}^{-2}$ in Chihuahuan Desert. Radiation does not seem to be a major constraint for photosynthesis of *G. sarothrae*.⁽²⁶⁾ Annual precipitation is also similar for three of the four *G. sarothrae* habitats (Table 1). However, there is a significant difference in the seasonal distribution of precipitation in the habitats of the northern vs southern populations. In the Great Basin Desert, it rains mostly in the spring, while in the southwest, in the summer and fall (Fig. 4). Plants must grow during the period when there is an adequate supply of water. In the Great Basin, maximum monthly precipitation in the spring is only 40 mm (Fig. 4), which, if it occurs in two rainfall events, can barely wet the 30-cm soil profile. The Idaho population, therefore, must have a high root density in the topsoil to secure water from light rainfalls, as suggested by Weaver.⁽²⁸⁾ This agrees with the current study in that water depletion from topsoil by the Idaho population was higher than the Plains population and comparable to those depletions by the Jornada and Mountainair populations. Root length of the Idaho population in the 30-cm topsoil was also greater ($P < 0.05$) than that of the Plains population (Fig. 3). This is consistent with observations that other Great Basin Desert species maximized their root growth within the top 30-cm soil in the spring.⁽²⁾ In the cold desert, much of the precipitation in fall and winter comes as snow that often recharges the soil profile. However, soil water depletion in spring primarily occurred in the top 30 cm of soil,⁽²⁾ suggesting the importance of spring precipitation on shallow root development of the northern population of *G. sarothrae*. It is also possible

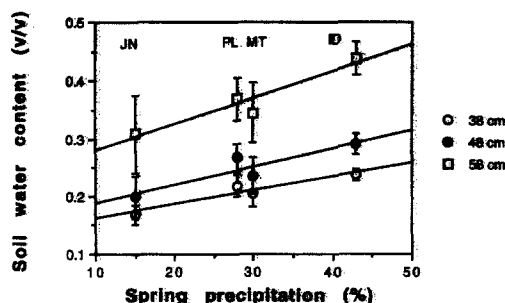


Fig. 5. Relationship between moisture content in the lower pots and the proportion of the annual precipitation that occurs in spring (March–May). The vertical bars are ± 1 standard error of mean. ID—Malta, Idaho; PL—Plains, Texas; MT—Mountainair, New Mexico; JN—Jornada, New Mexico.

that because of competition from dominant shrubs, there may have been selection pressure for *G. sarothrae* to extract surface moisture rather than to directly compete. But spring precipitation has a direct effect on surface moisture and consequently, plant rooting patterns.

In contrast, the southern seedlings may have to accelerate root penetration into the subsoil where stored water from fall and winter precipitation exist for plants to survive a relatively dry spring. Therefore, the early vertical root extension in some southern populations is an important adaptation to their environments. Furthermore, most grasses start growth in the spring and they generally have more roots in the topsoil than shrubs.^(4,19) This should also allow shrubs to partition soil water with grasses early in their life cycle when competition from grasses is intense in the topsoil.^(1,26) The positive relationship between proportion of spring precipitation (March–May) and water content in the deeper soil profiles (Fig. 5) is perhaps the best indicator of how a dry spring promotes early vertical root extension. The larger roots of the Jornada population elongate at faster rates than the smaller roots of the Idaho population. This is in accordance with the work of Ekanayake *et al.*⁽⁸⁾ who showed that rice cultivars with larger roots were likely to have longer root systems and were more drought resistant than drought susceptible cultivars which had smaller, shallow roots. Larger roots are capable of translocating more photosynthates to their root tips to help maintain faster growth rates.⁽¹⁴⁾ This, however,

is in contrast to the work of Eissenstat⁽⁹⁾ and Eissenstat and Caldwell⁽¹¹⁾ who demonstrated that species with smaller diameter roots had more rapid root penetration into disturbed soil.

Among the four populations studied, the Plains population had fewer roots ($P < 0.05$) and took up less water from the topsoil. Plains, Texas had at least 48% more annual precipitation and at least 43% more rainfall in the fall (Fig. 4) than the other natural habitats of broom snakeweed. There might be more water from fall precipitation stored in the deeper soil layers.⁽²⁷⁾ The Plains population had a tendency to have more roots deep in the moist subsoil, but significantly restricted root growth in the drier topsoil (Fig. 3), so water in the moist subsoil could be depleted efficiently.

In addition to extensive root systems, greater water extraction by the southern populations from the deeper soil may also be facilitated by their thicker roots which are linked to wider xylem vessels^(5,29) and, hence, a lower axial resistance to water flow. The radial resistance was not assumed to be large because of the minimal root suberization at the early stages of root development and in the moist growth medium (root suberization has not been observed).

The Idaho population had less green photosynthesizing surface area than the southern populations (193 vs 319–389 cm², $P < 0.05$). Canopy size in Idaho populations was probably constrained by the plants' inability to deplete the lower soil strata. Since the deeper soil was much wetter than the topsoil (Fig. 1), this effect was manifested. Larger canopy size in the southern populations must be supported by deeper rooting where direct tapping of subsurface stored water and hydraulic lift can become possible. This is consistent with the recent work of Reader *et al.*⁽²⁰⁾ who illustrated that species with greater plasticity in rooting depth showed greater ability to sustain leaf growth in unwatered soil.

Greater canopy sizes of southern populations suggested that mid-season canopy growth appeared to be related to rooting characteristics and predetermined by summer precipitation patterns (environmental stimulus). This seems to be supported by the field observations which indicated that a snakeweed population in the Great Basin sheds most of its leaves in the summer,⁽⁷⁾ while a Texas population sheds only 20% leaves in the summer dry season.⁽²⁶⁾

In summary, our hypothesis has been partially supported. Seedlings of Idaho *G. sarothrae* depended primarily on shallow roots for water uptake; they extracted significantly less water from soil depths ≥ 38 cm than the southern seedlings. Water uptake from soil depths ≥ 38 cm accounted for a very large portion of water consumption in the southern populations which generally had larger root diameters than the northern population. Accelerated vertical root extension was evident in some southern populations. On Texas rangeland where subsurface stored water in spring is more available, *G. sarothrae* plants tend to have a reduced shallow root growth. The different water acquisition patterns in southern vs northern populations appeared to be related to seasonal distribution of precipitation in their respective environments.

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